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ADVISORY GROUP FOR AERONAUTICAL RESEARCH AND DEVELOPMENT

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UNITED STATES NAVY PILOT-CONTROLLED LANDING PROCEDURE AND ASSOCIATED EQUIPMENT

by

J. H. NELSON & G. M. GRIFFIN

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NORTH ATLANTIC TREATY ORGANIZATION

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UNITED STATES NAVY PILOT-CONTROLLED LANDING PROCEDURE AND ASSOCIATED EQUIPMENT

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J.H. Nelson and G.M. Griffin

This Report was presented at the Aircraft Take-Off and Landing Specialists' Meeting, sponsored by the AGARD Flight Mechanics Panel, held in Paris, 15-18 January 1963

SUMMARY

The constant glide slope power approach to landing is defined as establishing the airplane in the desired landing condition early in the landing maneuver and maintaining this condition to touchdown. Reasons for the U.S. Navy adopting this procedure are advanced. The applicability of the procedure to non-carrier based fixed-wing airplanes is discussed.

Various optical and electronic devices, including an approach power compensator, which can aid the pilot in executing the discussed procedure are fully described. The effectiveness of each device, integral or external to the airplane, in presenting airspeed, glide slope, line-up, bearing and range information to the pilot under VFR and IFR conditions is delineated.

SOMMAIRE

L'approche d'atterrissage avec moteur sur chenal de descente constant est défini comme éstablissant l'avion dans l'état d'atterrissage désiré au début de la manoeuvre d'atterrissage et conservant cet état jusqu'à l'impact au sol. On présente les raisons ayant motivé l'adoption de cette procédure par la Marine des U.S.A. On discute l'applicabilité de cette procédure aux avions à ailes fixes et n'ayant pas le porte-avions pour base.

On décrit complètement divers dispositifs optiques et électroniques, notamment un compensateur d'approche avec moteur, qui peut aider le pilote à exécuter la procédure examinée. On esquisse l'efficacité de chacun de ces dispositifs, incorporé à l'avion ou extérieur à celui-ci, pour présenter la vitesse propre, le chenal de descente, l'alignement, les informations de relèvement et de rayon d'action au pilote pour opérer suivant les règles de vol à vue ou de vol aux instruments.

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UNITED STATES NAVY PILOT-CONTROLLED LANDING PROCEDURE AND ASSOCIATED EQUIPMENT

J.H. Nelson* and G.M. Griffin†

1. INTRODUCTION

The shipboard recovery of present day jet airplanes is a continuously developing procedure, constantly requiring solutions to new problems and the search for problem areas as yet unrecognized. The techniques and associated equipment are constantly being revised, improved and modernized to keep pace with the airplane. This report will discuss the evolution of the United States Navy's present landing technique and some of the associated shipboard and airplane equipment.

1.1 Background

The United States Navy aircraft carrier landing from the first days of carrier aviation until the early 1950's consisted of the 'flat paddles approach' technique. Using brightly colored paddles the Landing Signal Officer (LSO), located on the port side of the flight deck ramp, signaled information to the approaching pilot, indicating the quality and errors of his approach. As the airplane approached the ramp, a visual signal was given by the LSO to the pilot to 'cut' his engine and land the airplane. This short, critical time period from release of LSO control to airplane touchdown was made hazardous by the variables and transition which were not always precisely controlled by the pilot. The 'flat paddles approach' was the best available technique for the straight-deck carriers, due to the limited touchdown area and the lack of a touch-and-go capability for salvaging long touchdowns. Through the years approach speeds varied from 60 knots to 90 knots and shipboard engaging speeds were generally quite low.

The first operational carrier-based jets (straight wing) flew at recommended approach speeds in the 100-115 knot range. For these airplanes, ultimate sinking speed was 17 ft/sec and arresting gear limitation and/or airplane structural considerations dictated engaging speeds in the 85-100 knot speed range. A longer pattern could and did provide for the pilot sufficient time to effect proper line-up and approach altitude. The higher closing speed, however, reduced to a marginal point the time during which the LSO could advise the pilot of flight path errors.

During the early and mid 1950's the advent of the angled-deck carrier, the tricycle-geared airplane and the adoption of the mirror optical landing system brought about the discontinuance of the 'paddles' technique and introduced the present day technique of a constant glide slope approach to touchdown. The United States Navy's adoption of the constant glide slope technique was part of a revolution in carrier landing procedures triggered, not only by the advent of the angled deck and mirror optical landing aid, but by the belief that airplane structural loads could be reduced or, at least, be held to a reasonably predictable range.

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The angled deck increased the latitude of the touchdown area, namely, in the long landing regime and added bolter capability. The mirror provided for a constant glide slope technique and increased the range of glide slope information beyond the LSO's visual capacity. The mirror did not provide as much information to the pilot as did the LSO, but its lack of human error and greater range were felt to outweigh what disadvantages it had. In addition, the mirror and constant glide slope technique offered these clear advantages:

(a) The mirror, due to its larger size and greater illumination, provided elevation information at ranges considerably greater than that which the LSO could furnish.

(b) In descending on a glide slope the pilot's visibility forward was improved due to the slightly nose down attitude of the airplane.

(c) The area under the altitude versus range-to-touchdown curve (a measure of safety, particularly at night) was increased.

(d) The airspeed could be better stabilized at the proper value by the pilot (it was believed) thus reducing the incidence of airplane or arresting gear failures due to excessive engaging speeds.

(e) The airplane could be stabilized in the proper landing attitude and established on the proper landing sink rate early in the approach. The pilot need only maintain the landing variables at constant values and there was no need for the hazardous transition to landing.

In spite of these advantages, however, with the advent of the high performance jet airplanes of the mid 1950's (approach speeds 120-135 knots) it soon became apparent that the new technique with existing equipment was not a panacea for shipboard operations.

1.2 The Technique

The reader is referred to Figure 1. Here, in a plan and profile view, is presented the constant glide slope carrier landing geometry. Such arbitrary restrictions as the imaginary 10-foot obstacle at the ramp to be cleared by the tail-hook and the port and starboard 20-foot maximum lateral offset limits are imposed in the realization that the theoretically perfect approach will always be compromised by such factors as turbulent wind-over-the-deck (WOD), motion of the deck and pilot-induced variables.

The glide slope used aboard ship is usually 3½ or 4 degrees. The maximum 4-degree angle is dictated by the structural loads on the airplane imposed by the vertical sink speed. The minimum glide slope angle is dictated by several factors:

(a) The airplane must clear the ramp for a steady deck condition by a minimum distance of 10 feet to allow for safe ramp clearance during pitching deck conditions and pilot deviation from the desired glide slope. The length of the flight deck limits the distance that the arresting wires may be set forward of the ramp; therefore, this geometry of a ten foot ramp clearance and wire location sets a limit to which the glide slope may be lowered and still arrest the airplane.

(b) The shallower the angle becomes, the greater the dispersion in touchdown with glide slope error due to the simple trigonometric relation. The ground effect for some airplane models is more pronounced on touchdown dispersion for the shallower glide slope angles.

(c) It has been qualitatively determined that for the shallower angles, those of less than three degrees, pilots find it more difficult to accurately maintain desired glide slope than for the slightly steeper angles.

A constant vertical error displacement from the desired glide slope results in longitudinal touchdown dispersion from the desired touchdown point. This point aboard ship is normally between the second and third arresting pendant. If the error exceeds 5 feet above the desired glide slope the airplane will bolter; whereas, 5 feet below the desired glide slope places the airplane in dangerous close proximity to the flight deck ramp.

A constant angular error or sudden divergence from the desired glide slope results in longitudinal touchdown dispersion and introduces undesirable variations in the predicted sink speed. As stated above, one of the reasons for adopting the constant glide slope approach technique was because it was believed that sinking speeds could be precisely controlled and would be predictable.

A constant lateral error from the desired landing centerline results in off-center touchdowns and arrestments. The limiting arresting gear speed decreases as the off-center distance increases and the possibility of other undesirable effects, such as catwalk crashes, varies in degree with the different airplane/arresting gear combinations. Therefore, it is mandatory to land as close to the centerline as possible.

An angular error with respect to the centerline should be avoided to prevent possible loss of the airplane over the side during airplane roll out. Maintaining line-up, especially during the final phase of the approach, is important to prevent the necessity of large last-second corrections in line-up. Such corrections can cause large airplane roll angles during touchdown with potentially catastrophic results.

2. TODAY'S PROBLEMS AND APPROACHES THERETO

As was previously stated, the rather revolutionary change to the angled deck, mirror optical landing aid and constant glide slope technique has proved to be no panacea. Today's airplanes, heavier still, are approaching in the 130-150 knot range of airspeeds. Ultimate sinking speeds are now 24 feet per second. Arresting equipment capacity has been increased. The size of the landing area, however, has not been significantly increased. Some of the modern airplanes are operating in the flat portion of the thrust required curve and tend toward speed instability. Net result has been a narrowing of the margin for error.

The two most common accidents can be described as follows:

(a) *High at the ramp, dive for the deck.* This accident typically begins when the pilot gets below the glide slope at 1 mile or more. Over-correction of this

error (due in part to an inability to precisely judge the magnitude of the error at long range) results in crossing the ramp above the glide slope. He pushes over to insure getting a wire and the resultant high sink rate causes structural failure.

(b) *Ramp crash.* This accident is often caused by a fast start above the glide slope. Thrust is reduced to allow the airplane to settle back onto the glide slope. Thrust is then added to stop excessive sinking, but too late, for the inertia of the airplane has caused it to settle below the glide slope. Rotation to a higher angle of attack only aggravates the problem.

A variation of the two types of accidents described above occurs as a result of late recognition of line-up errors. The roll angle required to effect satisfactory correction will at times still exist at touchdown resulting in landing gear structural failure.

In the above discussion note that the types of accidents described began with poor starting conditions and were contributed to by an inability on the part of the pilot to recognize the deteriorating condition of his approach. Required, therefore, are devices or systems which will not only enable the pilot to make a good start down the glide slope, but which will enable him to more quickly perceive and correct errors during the approach. A part of the design criteria for airplane landing gear loads is depicted in Figure 2. Note that with 7 degrees of roll angle at touchdown, the sink speed above which failure can be expected to occur is reduced to 50% of its 'wings level' value.

Today the night accident rate is 4 times the day rate. This fact appears to be due primarily to two factors:

(a) Training in night carrier landing operations has never been as thorough or rigorous as for day operations. Therefore, the average pilot is not, so to speak, 'at home' in the night environment.

(b) Darkness blots out most visual clues to attitude, altitude, range, closing rate, et cetera, which help to cue the pilot as to the situation existing at any instant. Little progress has been made as yet in providing replacement cues for night operations.

At present, deck painting during daylight and center-line lighting at night provide the only line-up information available to the pilot. TACAN or CCA instructions can provide reasonably accurate line-up information to within one mile of the carrier in poor visibility conditions, but the pilot must take over visually during the final stage of the approach. As stated earlier, late line-up may cause large roll angles on touchdown.

Recent investigations of the airflow astern of the ship show that the disturbance of this airflow just aft of the ramp and in the landing area adversely affects the pilot's ability to keep his wings level or keep his airplane on the recommended glide slope. The disturbed airflow or 'burble' as it is called, which is illustrated in Figure 3 sometimes causes violent wing drops as the airplane crosses the ramp.

Any discussion of what approaches have been made toward providing improved landing aids for the pilot must start with the mirror optical landing aid.

2.1 The Mirror Landing Aid

The mirror is a portion of a four foot high cylinder, having a radius of ten feet with its concave surface directed toward the approaching airplane. It reflects a virtual image of a group of source lights in a fan-shaped beam oriented at a selected glide slope angle with reference to the horizontal by slightly inclining the vertical axis of the mirror's cylindrical section.

Arranged on either side of the mirror on a line horizontally bisecting it are two rows of green datum lights. By maintaining the image of the orange source lights or 'meatball' on the same line as the datum lights, the pilot holds his airplane on the desired glide slope.

The total vertical angle of the usable information conveyed by the mirror is $1\frac{1}{2}^{\circ}$. However, due to the limited size of the mirror surface and the datum bars, resolution of the glide slope information by the human eye is impossible beyond a range of approximately 1½ miles. Conditions of poor visibility will reduce this figure.

One of the greatest limitations of the mirror, as it is presently incorporated on U.S. Navy ships, is its limited stabilization capability. The mirror stabilization system provides for a stabilized point on the desired glide slope 2500 feet aft of the landing ramp. As the airplane travels down the glide path at lesser ranges, the quality of stabilization received deteriorates. At the ramp the stabilization is not of sufficient quality to give proper guidance to the pilot during pitching deck conditions.

In addition to the limited range of meatball resolution and marginal stabilization the mirror does not provide the other parameter of guidance information, that of line-up. The fact that the mirror is off-set to one side of the intended landing area and demands a good deal of concentration causes distraction of the pilot from attention to line-up and control of airspeed/angle of attack.

2.2 The Fresnel Lens

A somewhat superior optical landing aid recently developed is the Fresnel lens. To the pilot the Fresnel lens appears similar to the mirror and, for all practical purposes, reacts just like the mirror. It is a four foot high vertical column of five separate lenses and integral source lights which appear as one continuous lens and projects a real image of the 'meatball' rather than a reflected one. The Fresnel lens is lighter weight, less bulky and eliminates some of the topside obstructions which are inherent in the mirror. Its 'meatball' is more reliable because of the integrated source light, but its viewing characteristics in range of glide slope error indication and meatball resolution are quite similar to the mirror. The stabilization system presently used is similar to the mirror, that is, point stabilized. Under pitching deck conditions at night with a point stabilized optical landing aid, the pilot's only recourse is to attempt to average meatball movement.

A later version of the Fresnel lens will incorporate a greatly improved stabilization system. This improved system can provide a fully stabilized glide slope throughout the entire glide path range. This new 'line stabilized' system has been evaluated, found to be satisfactory and will be in operational use in the very near future. Improved landing safety is anticipated with its use during pitching deck conditions.

An approach to simplifying the pilot's task of monitoring and controlling airspeed was provided by the adoption by the United States Navy of the angle of attack measuring system.

2.3 Angle of Attack Measuring Systems

The landing weights of jet airplanes usually vary through several thousand pounds. Angle-of-attack has been found to be superior to airspeed as a parameter for use in maintaining speed control. The recommended angle-of-attack for approach is a constant and provides the optimum airspeed irrespective of variations in gross weight. The angle-of-attack indicator provides direct readout of arbitrarily established angle-of-attack units.

In general, superior angle-of-attack information is provided with displays which are actuated by an Airstream Direction Detector (ADD). United States Navy angle-of-attack sensors have been of 3 basic types:

(a) Airflow pressure sensors which sense stagnation point pressure.

(b) Vane type ADD which protrude from a vertical surface on the forward fuselage.

(c) Probe type ADDs which are also located protruding from the vertical surface of the forward fuselage. The primary disadvantage of both airspeed and angle-of-attack indicators is the lack of ready display to the pilot. Both indicators are located within the cockpit below the glare shield. This position requires the pilot to refocus his eyes back inside the cockpit below the glare shield and complicates his scan pattern of mirror, line-up and airspeed.

2.4 The Angle-of-Attack Indexer

The Indexer is an angle-of-attack display instrument. It is located above the glare shield within the pilot's peripheral vision as he looks through the forward canopy. The Indexer shows deviations from the optimum angle-of-attack by a display of three small symbols. They are in the form of a circle with a 'vee' above and chevron below it, which, when illuminated, indicate airspeeds of fast, slightly fast, on speed, slightly slow and slow.

The significance of the angle-of-attack Indexer is greater than its rather simple function would seem to indicate. It represents a first attempt to display cockpit information in a form and position conducive to acquisition by means of pilot's peripheral vision. Thus, it enables the pilot to receive glide slope information from the mirror and line-up information from the deck centerline without having to refocus his eyes or move his head to check up on angle-of-attack or airspeed.

3. FUTURE EQUIPMENT

Previous discussion indicates that improvements are required in shipboard landing equipment. The question arises as to what design requirements these improved equipments should meet. As noted above, the United States Naval Aviation Safety Center has determined that, all other factors being equal, the night carrier landing

accident rate is four times higher than the day rate. Note that these figures presume an equal probability of poor weather conditions by day or by night. Data from the United States Naval Weather Service indicate that in most areas of the world's oceans, the ceiling and visibility will be less than 200 feet and 1/2 mile less than 2% of the time. In the worst area, the North Atlantic, these conditions will prevail no more than 5% of the time. Ceiling/visibility conditions of 300 feet/1 mile will occur in most areas less than 5% of the time with only the East coastal area off Formosa exceeding this figure. The effect on carrier operations of potentially adverse weather is, undoubtedly, lessened by the carrier's mobility. Therefore, the development of aids and equipment which will improve the safety of the night fair-weather carrier landing will provide the greatest potential reduction in the landing accident rate.

Moreover, recent data have shown that the quantity of three standard deviations of the deviation from theoretical sinking speed for the constant glide slope approach aboard ship will vary from 4 to 10 feet per second. If the theoretical sink speed for a certain combination of approach airspeed and glide slope angle is 12 feet per second, deviations can be expected to reach as high as 22 feet per second. These deviations from theoretical sinking speeds can be attributed directly to divergence from the desired glide slope. As stated before, a good start, well out on the glide slope is half the battle.

3.1 The Hi-Lo Cells

The first attempt to aid the pilot toward the glide slope when he was beyond a range of 1½ miles (beyond the range of meatball resolution) was the Hi-Lo cell. The original Hi-Lo indicator consisted of a pair of flashing light beams, one mounted above and one below the vertical $1\frac{1}{2}^{\circ}$ spread of the mirror optical landing aid. In the United States Navy's version these beams are each vertically 2° in height with the upper cell flashing at the rate of 160 times per second. This system helps to funnel the pilot onto the glide path; however, if he is above or below the Hi-Lo beams he has no information. The difficulty in stabilizing these heavy cells during pitching deck conditions prevents them from becoming operational.

The latest and most successful type of Hi-Lo cell is used in conjunction with the Fresnel lens. Instead of mounting cells on the top and bottom of the Fresnel, the present top and bottom cells of the Fresnel are modified. This modification consists of changing the color of the present orange filter to red or white. Thus, even when the pilot is beyond the range of being able to tell whether the meatball is high or low due to its position he at least can tell whether he is very high or low by the color of the meatball. The cells, being a part of the Fresnel, are already stabilized. Further improvements of this system are being investigated.

3.2 The Approach Power Compensator (APC)

The problem of maintaining speed control and optimum position on the glide path is compounded during the approach to the carrier in some United States Navy airplanes because they have neutral airspeed stability, e.g. there is negligible change in thrust required over a range of airspeeds. A significant stride has been taken in an attempt to improve this situation by the development of the APC or Auto-throttle. Equipment by three manufacturers has been or is now under evaluation at the United States Naval Air Test Center. Of these three, two are primarily airspeed sensors and

one is an angle-of-attack device. The airspeed-sensing systems function to maintain the reference airspeed which exists at the time the pilot engages the system. The angle-of-attack sensing APC has a dial for selecting the desired angle-of-attack. Once this is set and the system is engaged, it varies thrust as required to maintain the pre-selected angle-of-attack. All systems have some form of secondary input such as normal acceleration, pitch rate or pitch acceleration. When flying an airplane equipped with APC the pilot need no longer concern himself with speed control during the approach. Because of the advantages of this equipment a form of APC will ultimately be incorporated in all United States Navy carrier airplanes.

3.3 The Electronics Glide Slope (EGS)

The EGS provides a cockpit presentation of vertical and lateral glide slope error. During conditions of poor visibility it provides the pilot with a means of establishing himself on the proper glide slope before visual contact is made with the carrier. In its simplest form, a current which is a linear function of range to the ship's TACAN antenna and another current similarly representing altitude as measured by the radar altimeter are compared in a bridge circuit. These currents are attenuated during calibration such that the ratio of the range current to the altitude current is equal to the cosecant of the intended glide path angle. The bridge output is impressed on the horizontal bar movement of an Instrument Landing System type instrument. The TACAN azimuth information is conveniently displayed on the vertical bar of the same instrument in many Navy airplanes. Thus, when the two bars are centered, the airplane is approaching the TACAN station on the selected glide slope. Aboard ship with the TACAN station located near the landing area, the pilot is capable of approaching the ship from a distance of 15 miles utilizing EGS to within 3/4 mile and 300 feet before having to transit to visual aids. During night fair-weather conditions the EGS guides the pilot to a position from which he may easily transit, or make a 'good start' using visual aids to complete his approach to a safe landing. EGS can be easily and inexpensively installed in any airplane which is equipped with TACAN and radar altimeter. It is a step forward in improving the all-weather capability of carrier aviation. It could be an even better step if radar altimeters and TACAN equipment were more reliable and the accuracy of distance measuring of TACAN were improved.

For shore-based use the EGS, in its present form, has certain limitations. The radar altimeter, measuring terrain clearance, will generate a glide slope which tracks the terrain. For those airports with surrounding irregular terrain this is obviously undesirable. Most airports have their TACAN station located some distance from the runway which is also undesirable for EGS. For shore-based use a suitable variation of EGS might be devised which receives its altitude inputs from an accurate and reliable barometric altimeter, if such a barometric altimeter could be found and if TACAN stations were relocated adjacent to runway touchdown points.

3.4 The Data-Link Ordered Display

Probably, the most accurate landing aid presently under development is the data-link ordered display. This system, which is, actually, one operational mode of the United States Navy's Automatic Landing System, creates a display for the pilot which is quite similar to EGS or ILS. The information which is displayed, however, is ground-derived by precision tracking radar and computer and is transmitted to the airplane for display by means of a data link Basic to the system is a precision

tracking radar, whose output is airplane range, elevation angle and azimuth angle, and a computer which converts these spherical coordinates to cartesian coordinates and translates the origin to the desired touchdown point. The computer calculates the vertical and lateral errors and relays them to the airplane by means of the data link which may be any form of analogously or digitally coded radio frequency link. These error signals are decoded by the airborne data link terminal and displayed on the ILS type instrument. For shore-based use, this system is sufficiently accurate to be used all the way to touchdown under conditions of zero visibility. The data link ordered display is the most sophisticated and expensive of all systems under evaluation. Assuming equipment reliability it has the greatest promise of accuracy of any systems yet tried.

3.5 The Heads-Up Display

In the field of aids which provide the pilot simultaneously with all three of the principal parameters of the approach; namely, glide slope, line-up and airspeed/angle-of-attack, the 'heads up' display is currently under development. Figure 9 depicts the symbols the pilot sees on a gunsight type viewing plate mounted in the cockpit through which he views his intended touchdown point. The pilot maneuvers his airplane in order that the touchdown point pipper remains superimposed on his intended touchdown point and the angle-of-attack pipper remains opposite the right wing tip symbols. The display computer receives inputs of pitch and roll attitude, angle-of-attack and a nose-down biasing signal to create a preselected glide slope. The projected display is focused at infinity so that head motion does not adversely effect the glide slope.

While the 'heads up' display described above has its symbols actuated by airplane gyros and sensors, the basic display unit can have its symbols driven by any of several systems. Such a display actuated by either the Electronic Glide Slope system or by signals transmitted via a data link would provide the ultimate in informing the pilot of the status of his approach while simultaneously keeping his eyes focused on and looking toward the touchdown point.

4. THE SHORE-BASED ADAPTABILITY OF THE TECHNIQUE

The main theme of this Report has been concerned with the carrier-based airplane landing technique. Aboard ship the demands for touchdown and airplane control are more precise than for shore-based requirements. Yet, the United States Navy has found the techniques used aboard ship are suitable for shore-based use, especially for high-performance jet airplanes.

Unlike shipboard aids and equipment, little emphasis has been extended toward field landing aids. However, almost all Navy fields have installed some kind of visual glide slope device to aid pilots in both day and night landings. These are the shore-based mirror and Poor Man's Optical Landing Aid (POMOLA).

The shore-based mirror is similar to the shipboard mirror, only simpler in structural design and it excludes stabilization equipment. The Poor Man's Optical Landing Aid (POMOLA) consists of three billboard-shaped structures located on the side of the runway adjacent to the desired touchdown point. Two of the boards are set up side by side several feet off the ground to form a horizontal bar similar to the mirror datum bars. Approximately 50 feet down the runway, the third bar, representing

the meatball, is placed low to the ground and lined up with the other boards to form a three degree glide slope. The pilot maintains his airplane on a three degree glide path by keeping the meatball bar lined up with the datum bars during his approach.

The advantages in using the constant glide slope technique for shore-based use are similar to shipboard:

(a) The airplane can be stabilized early in the approach on proper landing airspeed, in the proper landing attitude and established on proper sink speed.

(b) The pilot has an extra degree of latitude in setting up these landing conditions while he is still several hundred feet above the ground. Once established, he need only maintain these conditions until touchdown. There is no need for trying to transition several variables to coincide at the proper instant of touchdown.

(c) The flight path of the airplane is more precisely defined. This results in less short-of-the-runway landings and long touchdowns which result in overruns or the need for excessive braking.

For those airplanes which cannot use the glide slope to touchdown due to landing gear geometry or inadequate structural strength, the initial portion of the approach can still be useful. The pilot may still establish himself on an airspeed and stabilized approach condition from which he can more consistently transit to a proper landing. Such a technique will result in smaller touchdown dispersion and a significant reduction in short touchdowns. Safety is the primary aim in improving landing techniques and equipment. In future design of shore-based airplanes it might be worthy of consideration that they be made suitable for a constant glide slope landing technique in order to fully benefit from its advantages.

5. CONCLUDING REMARKS

With the introduction of the angled-deck aircraft carrier and mirror optical landing aid, the present United States Navy carrier landing technique was born. Problems resulting from the introduction of high performance jet airplanes demanded that greater emphasis be placed on investigations of improved techniques and equipment. Development of night fair weather landing aid equipment and aids which will provide a multiplicity of information to the pilot will effect the greatest percentage reduction in the landing accident rate. Such equipments are now being introduced in the Fleet, or are now under evaluation, or are being developed.

The Navy's technique is, in different degrees, suitable for all fixed-wing airplanes. The approach phase can be used as an aid in transitions to better landings, less undershoots and decreased touchdown dispersion.

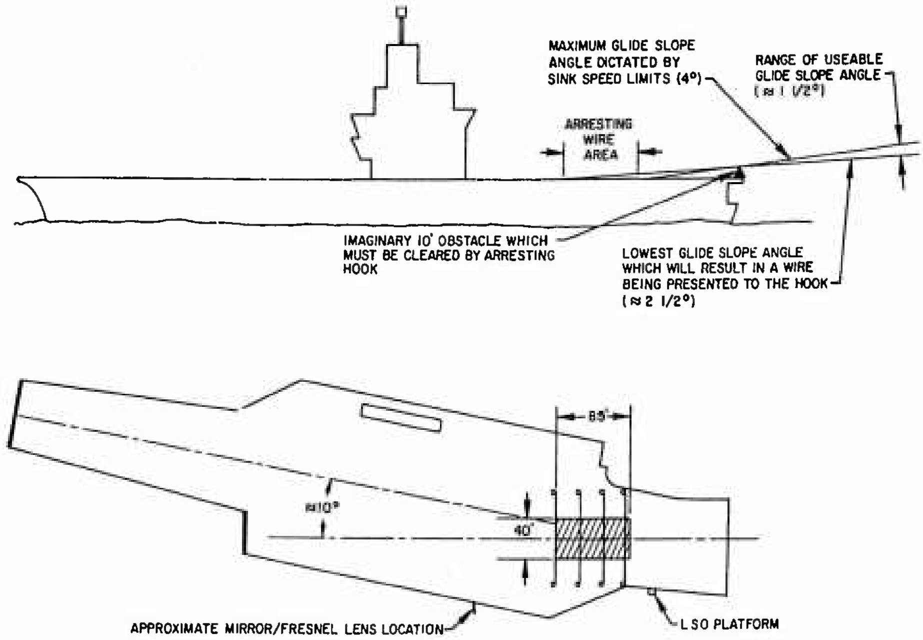

Fig. 1 Geometry of the carrier landing

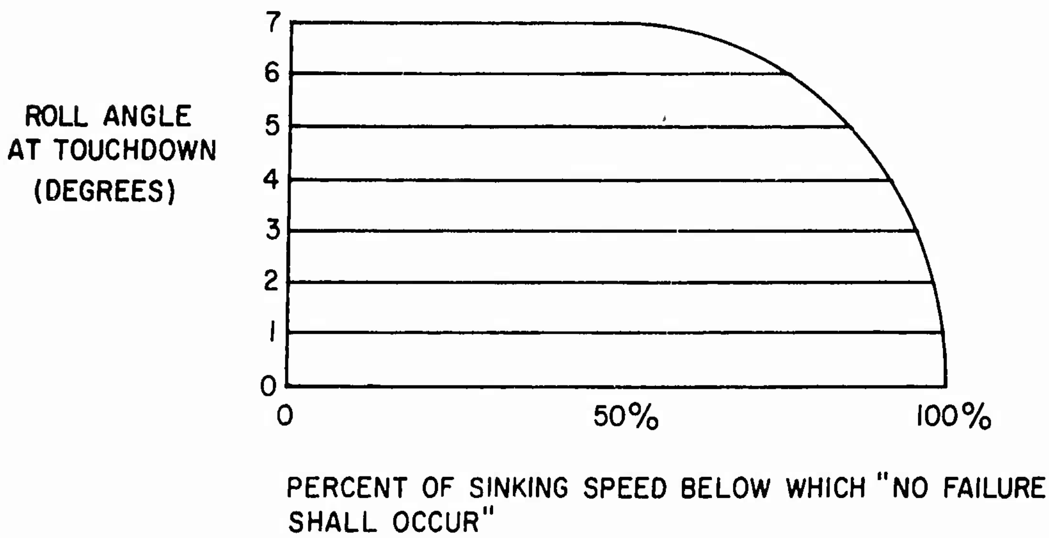

Fig. 2 Roll angle versus sinking speed. Design criteria for U.S. Navy carrier airplanes

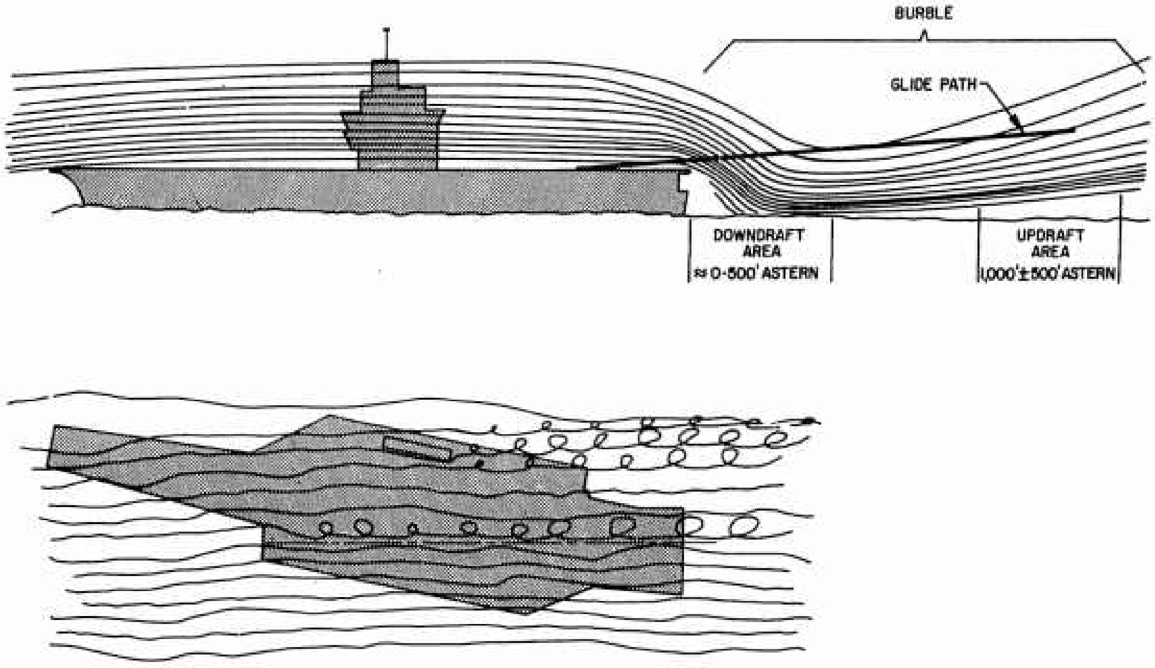

Fig. 3 Approximate pictorial representation of burble

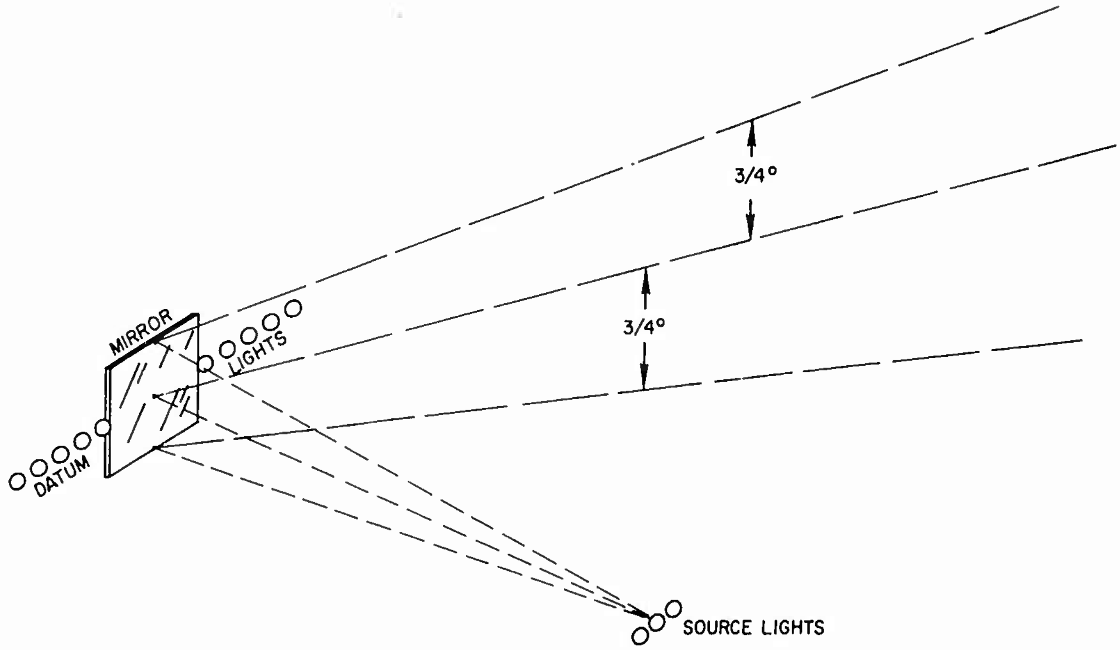

Fig. 4 Mirror optical landing aid

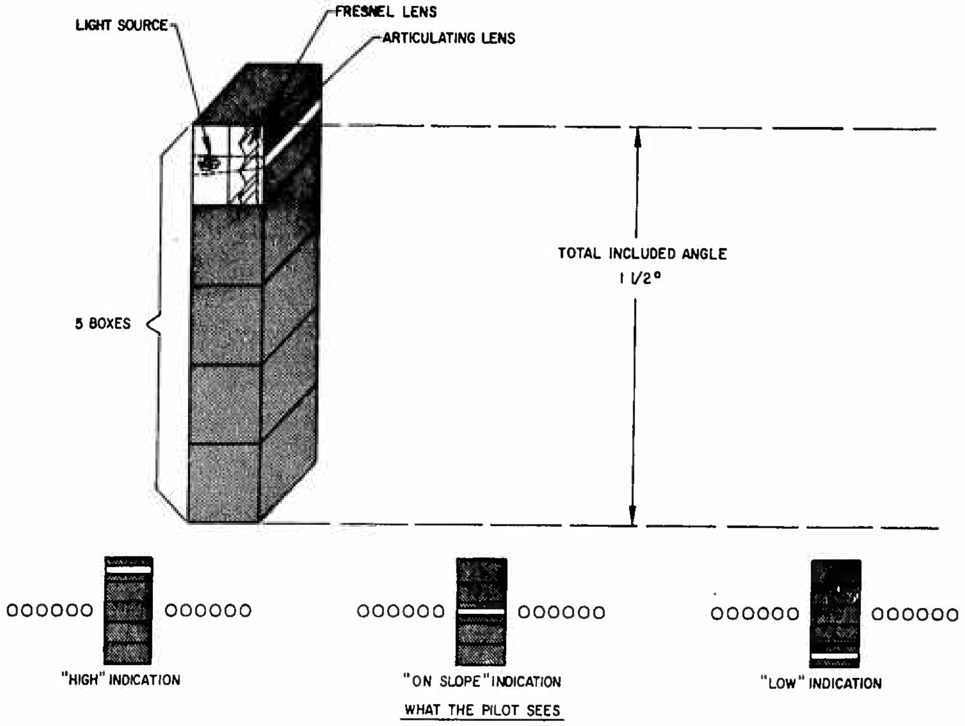

Fig.5 Fresnel lens

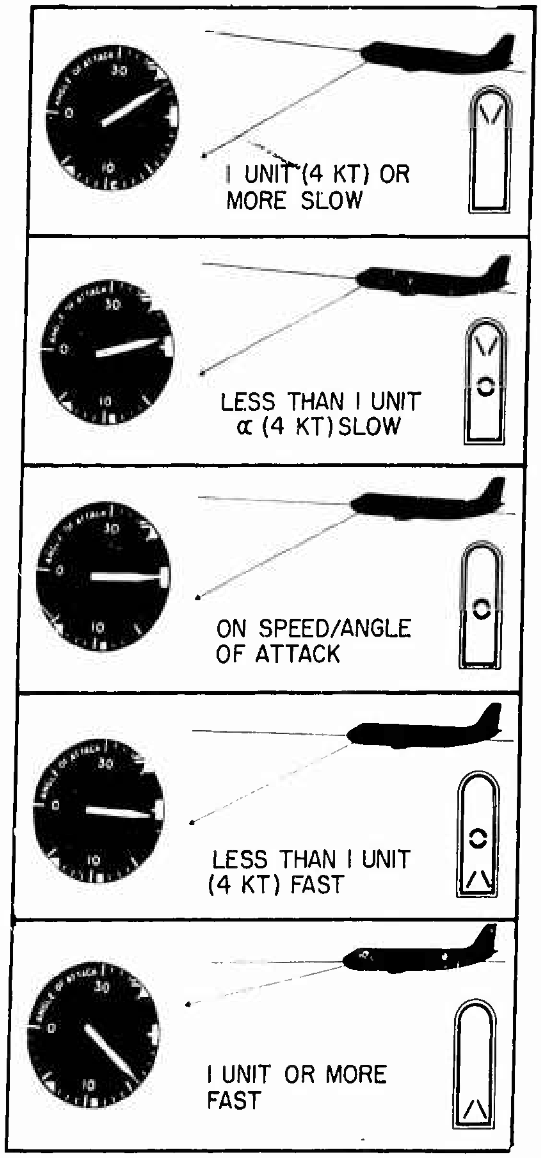

Fig.6 Angle of attack indicator/indexer displays compared

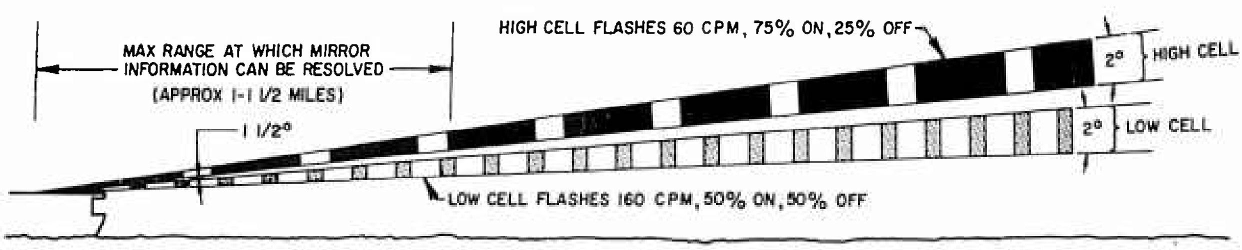

Fig.7 Geometry of high-low cell

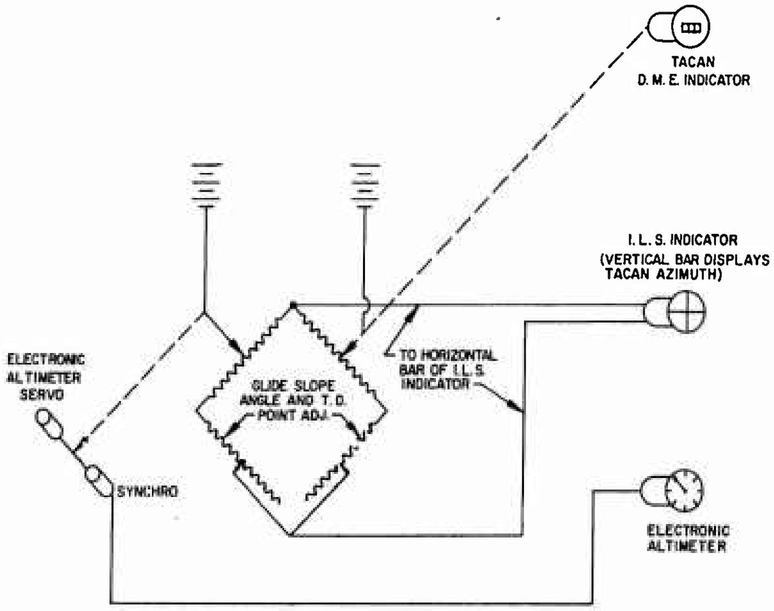

Fig.8 Simplified schematic of EGS system

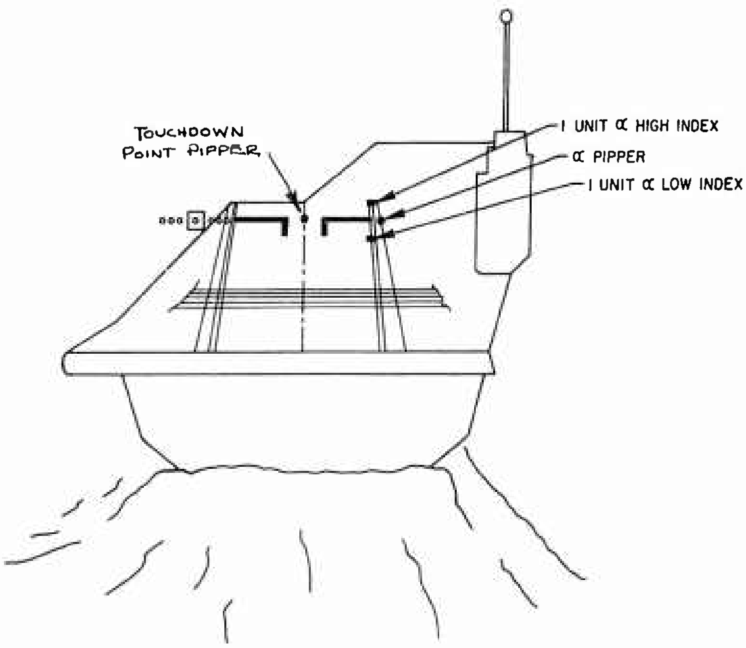

Fig.9 'Heads-up' display presentation

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